Machine Vision Detection of Early Split Pistachio Nuts

T. C. Pearson, D. C. Slaughter

Abstract. *Computer vision was used to detect early split lesions on the hull of pistachio nuts. Gray scale intensity profiles were computed across the width of the nut (perpendicular to the suture along the longitudinal axis). If the profile crossed an early split lesion, a deep and narrow valley on the profile at the early split location was observed. Profiles were computed every 0.5 mm along the longitudinal axis of the nut and the number of adjacent profiles with deep and narrow valleys was recorded. Early split nuts contained a significantly higher count of these adjacent profiles than normal nuts. Combining unhulled nut cross-sectional area with the adjacent profile data, 100% of the early split nuts and 99% of the normal nuts were correctly classified of the total of 180 nuts tested.*

Two devices were developed to convey and orient unhulled pistachio nuts for presentation to a computer vision system. One device, which operated similarly to an "air hockey" table, correctly oriented 98% of the early split nuts and 99% of the normal nuts. The other device, which used vibration to convey and orient the nut in a "V" trough, correctly oriented 97% of the early split nuts and 98% of the normal nuts. A total sample size of 270 nuts was used to test each orientation device. ***Keywords.** Pistachio nuts, Aflatoxin, Sorting, Machine vision.*

Pistachio nuts (*Pistacia vera*) have become an increasingly important crop in California over the past 20 years. From 1977 to 1991, the value of the pistachio crop increased from $4,680,000 to $100,716,000 (California Pistachio Commission, 1993). In 1992, 66 million kilograms of pistachio nuts were grown in California (California Pistachio Commission, 1993). Pistachio nuts are also an important export commodity. In 1992, the United States exported 11.7 million kilograms of pistachio nuts (California Pistachio Commission, 1993). Pistachio nuts have been shown to contain low levels of aflatoxin which could potentially make the commodity less attractive to foreign markets (Sommer et al., 1986). The European Community, where most of the pistachios are exported, is introducing more stringent regulations on aflatoxin content in foods. The basis of this research was to study the feasibility of automatically detecting nuts possibly contaminated with aflatoxin.

Pistachio nuts are characterized by a split on the shell along the suture and at the calyx end of the nut. This split normally occurs while the nut is on the tree about a month before harvest. The hull (mesocarp) of the pistachio usually encloses the shell and remains intact through harvest, serving as protection for the kernel after the shell splits open. However, about 1 to 4% of the time, the hull will adhere tightly to the shell and the hull will split open along with the shell. These nuts are called "early splits". The split on the hull allows an unobstructed passage to the kernel for airborne mold spores and insects, such as the navel orange worm, or small arachnids, such as mites, that might be carrying mold spores (Sommer et al., 1986). The mold *Aspergillus flavus*, which creates aflatoxin, can enter the nut through the early hull split. Sommer et al. (1986) found that early split nuts contain nearly all of the aflatoxin found in samples from pistachio orchards before harvest. Thus it is believed that the post harvest aflatoxin content of the pistachio commodity may be significantly reduced if the early split nuts are removed from the pistachio process streams. There is currently no processing operation performed to remove nuts contaminated with aflatoxin.

The prominent physical characteristic of an early split pistachio is a distinct, dark and smooth-edged split on the suture of the hull (fig. 1). When an early split occurs, the split will normally start at the calyx end of the hull and be present on only one side of the nut. Another kind of split that can occur on a pistachio hull shortly (less than 15 days) before harvest is called a growth split. Growth splits on pistachio hulls are characterized by ragged brown edges, and the split is randomly oriented and much wider than an early split (fig. 1). These nuts comprise

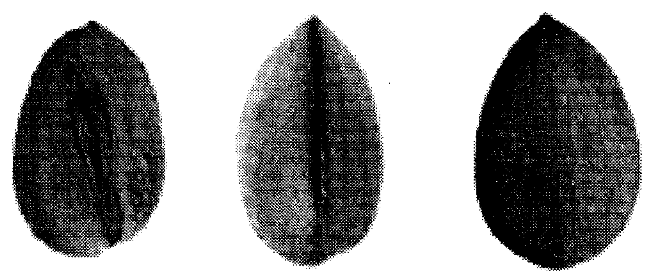

Figure 1–The three pistachio hull split types.

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approximately 20% of the entire pistachio crop. It has been shown that these nuts do not contain aflatoxin or *Aspergillus flavus* at harvest time, presumably because the mold has not had time to develop (Sommer et al., 1986). For this study, growth split nuts are also considered to be normal nuts along with nonsplit nuts.

There are several species of pistachio trees, but *Pistacia vera* is the only species in which the shell (endocarp) splits along the suture and produces fruits large enough to satisfy consumers. All of the marketed pistachios grown in the United States are of the 'Kerman' variety. Thus, only Kerman pistachio nuts were used in this study.

A plausible method for separating early split nuts from normal nuts is to detect early split lesions on the hull with a computer vision system. Several computer vision systems have been developed to inspect products at high rates. Ball Metal Container Corp. (Arvada, Colo.) has developed a computer vision system to inspect beverage cans for dents at a rate of 30 cans/s. Tang et al. (1989) developed a prune grading system that sorted prunes at a rate of 20 prunes/s. This system found discontinuities in intensity levels and correctly classified 95% of the prunes into three grades. Elster and Goodrum (1989) developed a system for inspecting eggs for cracks. Saridis and Brandin (1979) developed a system to inspect steel for surface defects at a feed rate of 10 cm/s.

Methods and Materials

Handling and Orientation of Pistachio Nuts

The problem of orienting and presenting products in a consistent manner for a computer vision system can be a complicated feat and often is the limiting factor for product throughput. An object, falling in air with velocities creating full turbulent flow, will assume the position of greatest resistance (Mohsenin, 1986). The suture plane of a pistachio nut is nearly always the widest part of the nut. Thus, a pistachio nut falling in air or floating in a vertically upward airstream would assume a position with its suture plane horizontal. This principle has been used to orient and convey many light objects in industrial environments. Ingraham and Pearson (1993) developed a conveyor that works similarly to an "air hockey" table. The conveyor is essentially an air duct with the top surface perforated with orifices to let air escape from the plenum and slightly lift the object to be conveyed. The perforations on the top surface, however, are louvered so that the air escaping the duct also has a horizontal component to push the objects downstream. This method of conveyance is successfully being used to convey small boxes, aluminum and steel beverage cans, bottle caps, and some food products such as chocolate confections. The conveyor can transport and singulate beverage cans at a rate of 2,000 cans/min.

To present the nuts for a computer vision system, two devices were developed. The first device, shown in figure 2, operates by blowing air upward, lifting the nut and orienting it so that the suture plane is horizontal. The air coming out of the air duct has a small horizontal component parallel to the "V" trough which conveys the nut. This device was constructed with a fan (Dayton, Chicago, Ill., E37403 – 1030 RPM) and a 30.5-cm-long duct at the fan outlet to stabilize the air flow. The inside dimensions of the duct were the same as that of the fan

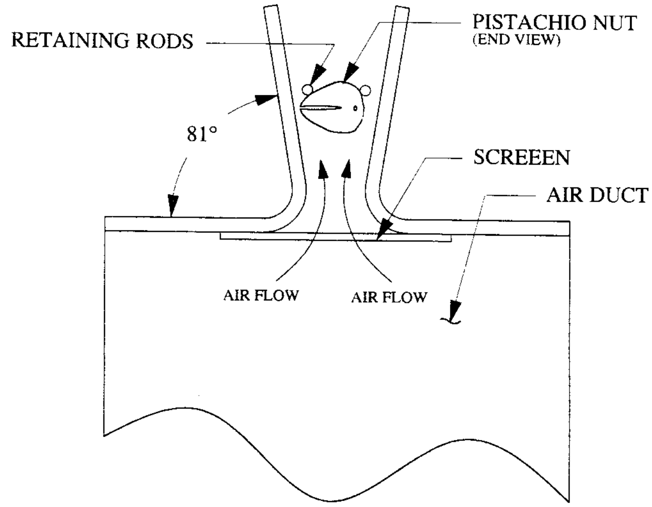

Figure 2–Pneumatic orientor.

outlet, 15.6 × 14 cm. The V trough was made from 12 gauge (2.67 mm thick) mild steel.

The second device implements a vibrating V to orient and convey the nuts. This was constructed by modifying a seed length sorter (Sortex, Union City, Calif., L1376). When a nut is dropped into the V, the vibrations convey the nut and orient it so that the suture is centered in the Vand the calyx end points down as shown in figure 3.

To test the orientation devices, 30 Kerman pistachio nuts of each split type from three different orchards (for a total of 90 nuts of each of the three split types) were collected during the 1992 harvest season. The nuts were placed into each device and it was noted if the nut properly oriented as shown in figures 2 and 3.

Equipment and Image Preparation

A second set of Kerman pistachio nut samples for use with image analysis were collected from the same three orchards previously mentioned. Twenty nuts of each split type were collected for imaging from each of the three orchards (for a total of 60 images of each of the three split types). The images were captured with an s-video camera (Kyocera, KD-H170U, Tokyo, Japan) and recorded on Sony Hi8 Metal-E video tape. The images were digitized with an Apple Macintosh IIfx computer equipped with a

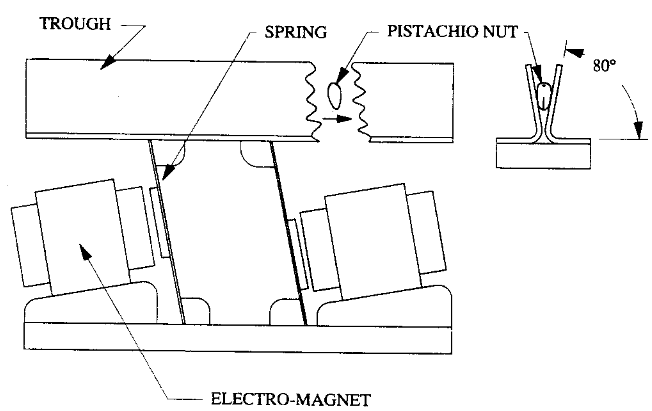

Figure 3–Vibrating V orientor – conveyor.

frame grabber (RasterOps, 24XLTV, Santa Clara, Calif.). The frame grabber had a built in s-video (Y/C) decoder. The s-video signals were input to the frame grabber by using the video camera as an s-video tape player. Alldrin (1994) provides a review of s-video systems and Benson (1986) provides a background of video image formats and systems. The images were digitized into 640 × 480 color image files with 256 intensity levels for each primary color (RGB) and stored in PICT format to conserve storage media space. All of the images were taken with the pistachio nut centered by hand on a white background under a fluorescent light ring 20 cm in diameter and the camera looking through the ring. The placement of the pistachios in all images was such that the suture was approximately in the center of the image and facing upward, towards the camera. About 80% of the nuts were oriented such that the angle between their sutures and the rows in the image was within ±20°, the remaining 20% of the nuts were aligned with an angle of ±20° to ±40° between their suture and the rows of the image. With this type of orientation, the suture and an early split lesion, if it exists, would be near the center of the image and approximately aligned with the rows of the image.

Growth splits can also occur on the suture of the nut, but they tend to be wider, shorter, and not as dark as an early split lesion. In addition, a growth split would very rarely lie directly on the nut's suture and be parallel with the long axis of the nut as is always true of an early split lesion.

A software package (Adobe Photoshop 2.5, Mountain View, Calif.) was used to crop images from 640 × 480 pixel images to 256 × 256 images and convert the files from PICT to TIFF format for processing. The image background was manually set to white (255 intensity) to ease identification of the nut region in the image. This was necessary because occasional problems with the white balance setting of camera caused the background to appear off-white in color in some images. The images were then loaded onto a UNIX-based engineering workstation (Sun Microsystems, SPARCstation model IPX, 40 Mhz, Mountain View, Calif.) for analysis.

Using the computer workstation, the images were converted to ASCII files, and converted from RGB images into gray scale. Only gray scale images were used in image analysis since there was no consistent difference in color between early split and normal nuts. Equation 1 was used to convert the RGB values to gray scale (Y) (Benson, 1986).

$$Y = 0.299R + 0.587G + 0.114B \tag{1}$$

where

Y = gray scale intensity level
R = red intensity level
G = green intensity level
B = blue intensity level

INTENSITY PROFILES OF PISTACHIO IMAGES

Intensity profiles of the nut were computed on every fourth column in the nut image. This spacing represented approximately 0.5 mm on the nut. Examples of typical profiles for nonsplit, growth split, and early split nuts are shown in figure 4 (the images have been rotated 90° for illustration purposes). As can be seen in figure 4, when a profile crosses an early split lesion, the profile minimum intensity is centered in the image; and, the profile minimum intensity is significantly less than the profile mean intensity.

For each profile examined, the profile mean and the mean of a 7 pixel (0.9 mm) segment centered about the minimum intensity pixel was computed. If the profile minimum was located within 13 pixels (1.6 mm) of the profile center and the mean of the 7 pixel (0.9 mm)

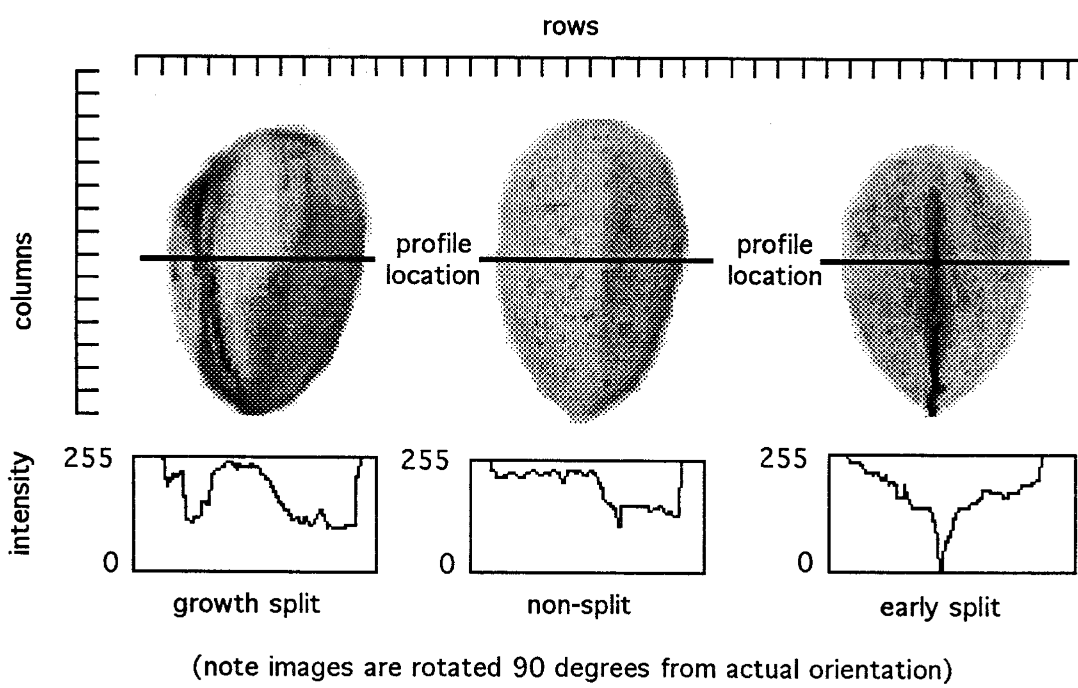

Figure 4–Typical pistachio nuts and gray level intensity profiles.

segment was less than 60% of the profile mean intensity, then this profile was considered to be crossing an early split. The maximum number of consecutive adjacent profiles meeting this criteria was counted for each nut.

The top edge of the nut was detected when the intensity level dropped below 255 (pure white) for at least two consecutive rows and the pixel 10 rows above was 255. This reduced the chance of false-edge detection caused by noise. Similarly, the bottom edge of the nut was detected when the image intensity returned back to white (255 intensity). The width of the nut was computed by subtracting the top edge row number from the bottom edge row number. The location of the center of the nut for a particular column was computed by adding the top edge row number to half of the nut width.

Early split nuts tend to be smaller in size than growth and nonsplit nuts. So, the number of pixels with intensities less than 255 were counted to get an approximation of the cross-sectional area of the nut.

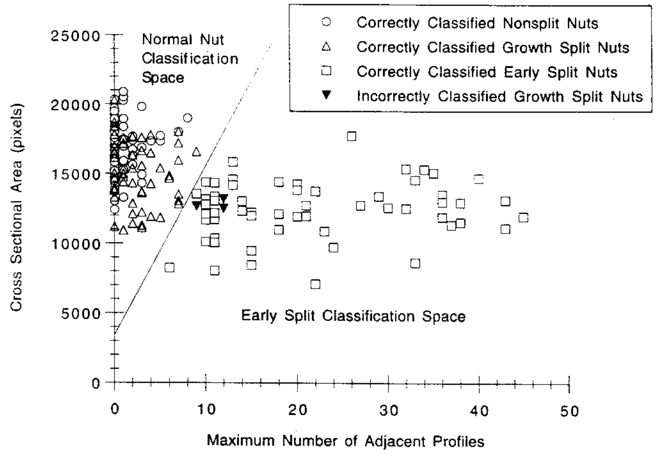

Figure 5–Graph of cross-sectional area vs. maximum number of adjacent profiles for nonsplit, growth split, and early split pistachio nuts.

RESULTS AND DISCUSSION

By combining the nut's cross-sectional area and the profile criteria, a high classification accuracy can be achieved. Figure 5 shows a plot of cross-sectional area (A) versus maximum adjacent profiles (MAP). Since the population of early split nuts is nearly separable from the normal nuts, a simple linear function can be used to classify normal versus early split nuts. These two features were used to classify the nuts into normal or early split types using the logistic procedure (SAS, 1989). When the probability threshold to classify a nut as an early split was set in proportion to the number of early split nuts in the data set (i.e., $p = 0.33$), 100% of the nonsplit, 100% of the early split, and 95% of the growth split nuts are correctly classified. The linear relationship dividing the early split classification space from the normal nut space is given in equation 2.

If [A < 3415 + 1217MAP]
Then Classify as an Early Split Nut
Else Classify as a Normal Nut (2)

where MAP is the maximum number of adjacent profiles and A is the cross-sectional area (pixels).

Three of the 60 growth split nuts reside in the early split classification space. Since growth split nuts comprise approximately 20% of the pistachio harvest, the 5% error rate for growth split nuts corresponds to a total error rate of only 1% of all normal nuts.

The classification algorithm is highly dependent on the early split lesion being centered between the top and bottom edges of the nut in the image. The MAP criteria was less sensitive to orientation errors in which the early split lesion remained centered between the top and bottom edges of the nut in the image than to errors where the early split lesion appeared offset toward one edge of the nut. Figure 5 shows that it is uncommon for normal nuts to have a MAP value greater than 10 (5 mm) indicating that an early split nut would need as little as 5 mm of its early split lesion located within ±1.6 mm of the major axis of the nut to be recognized. While the classification algorithm was sensitive to orientation errors where the nut was rotated about its major axis, it was not sensitive to the nut being rotated by as much as ±40° about either of the other two axes orthogonal to the major axis as long as the suture was centered "above" the nuts long axis in the image.

The orientation devices performed quite well. The pneumatic orienting device correctly oriented 98% of the early split nuts, 100% of the nonsplit nuts, and 96% of the growth split nuts. The vibrating V correctly oriented 97% of the early split nuts, 99% of the nonsplit nuts and 95% of the growth split nuts. An incorrectly oriented early split nut would likely be classified as a normal nut since the camera would not see the split region of the early split nut. Conversely, incorrectly oriented normal nuts would probably be correctly classified. Thus, if the pneumatic orienting device was to be used, 2% of the early split nuts would be incorrectly classified due to orientation errors.

The computer workstation was able to perform the classification algorithm at a rate of approximately 21 nuts per second (approximately 266 kg unhulled nuts per hour) excluding disk reading and writing operations. The orientation devices and detection algorithm are well suited for use with high speed line scan cameras. So, image capture and processing at speeds in the neighborhood of 266 kg/h may be possible.

CONCLUSION

The results of the computer vision investigation indicate that it is possible to distinguish early split pistachio nuts from nonsplit and growth split pistachios with a high accuracy. The image processing algorithm is able to correctly classify 100% of the early split nuts and 99% of the normal nuts assuming growth split nuts comprise 20% of the pistachio harvest and that the nuts were properly oriented. The pneumatic orienting device is able to properly orient 99% of the normal nuts and 98% of the early split nuts, again assuming that growth split nuts comprise 20% of the crop. Given that an incorrectly oriented early split nut would likely be incorrectly classified, an orientation and computer vision system would ideally be able to correctly classify approximately 98% of the early split nuts. Since the growth split and nonsplit nuts would still likely be correctly classified, even if they are not properly oriented, an orientation and computer vision system should, ideally, be able to correctly classify 99% of the normal nuts. Future research is needed to determine the actual classification accuracy of a complete real-time system.

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